Related Topics
Refractive index, wavelength, frequency, phase, modulation, heterodyne technique, electric field constant, magnetic field constant.

Principle
The intensity of a laser diode is modulated with a high frequency and the beam is reflected, after travelling some distance, back into the apparatus. The phase of the received signal is compared to the one transmitted. The velocity of light is then calculated from the measured phase difference, the modulation frequency and the length of the light path.

Equipment
1. Speed of Light meter (complete set) 11226-88
2. Screened cable, BNC, l = 750 mm 07542-11
1. Digital Oscilloscope 25 MHz, 2 channels 11456-99

Tasks
1. Determine the velocity of light in air.
2. Determine the velocity of light in water and calculate the refractive index.
3. Determine the velocity of light in acrylic glass and calculate the refractive index.

Fig. 1: Set-up of experiment
Set-up and Procedure

The light velocity measuring apparatus and the mirror are set up in such a way that the laser beam hits the mirror no matter where along the base the mirror is placed (more detailed directions can be found in the operating instructions of the Speed of Light meter). First the socket \( f_{\text{emmit}}/1000 \) is connected to the oscilloscope and the modulation frequency \( f_{\text{emmit}} \) (divided by 1000) is determined. The reason for introducing the fixed factor \( 1/1000 \) into the hardware between the modulator and the socket, is that a relatively simple oscilloscope can be used for the task.

After determination of the modulation frequency, the two other sockets \( (f_{\text{emmit}} - f_{\text{sync}} \) and \( f_{\text{rec}} - f_{\text{sync}} \) are connected to the two input sockets of the oscilloscope. The frequencies of the emitted and the received signal are also reduced to 50 KHz while conserving their phase relation so that they can be displayed on this type of oscilloscope.

**Task 1: The velocity of light in air**

At the start the mirror is placed close to the operating unit, the mode “\( \Delta \phi \)” is selected and the button “Calibration” is pressed to have two coinciding signals visible on the oscilloscope. (See Fig. 2)

The mirror is then slid along the graduated scale. For at least 10 different displacements \( \Delta x \ (> 100 \text{ cm}) \) the time difference \( \Delta t \) is calculated from the readings performed on the oscilloscope. (See Fig. 3).

**Task 2: The velocity of light in water and Task 3: The velocity of light in acrylic glass**

The water-filled tube or the acrylic glass rod is placed so that the laser beam runs through them, the mirror is placed directly behind. The “Calibration” button is pressed. Again the oscilloscope will show a graph similar to Fig. 2. The tube/rod is then taken out of the path of the rays, the two signals will not coincide any longer. Now the mirror is moved a distance \( \Delta x \) until the two signals on the oscilloscope coincide again as before with the medium inserted. The mirror displacement \( \Delta x \) is measured several times.

![Fig. 2. Oscilloscope signal after “Calibration”.

![Fig. 3. Measuring the time difference using the oscilloscope.](image)
Theory and evaluation

Although light travels very fast, its velocity is finite. Since 1676 when Romer estimated the velocity of light using spatial scales that included the distances to the moons of Jupiter much technical development took place. These days we can comfortably measure the speed of light on a table top. In the SI system, the metre is defined as the distance light travels in vacuum in $1/299792458$ of a second. The effect of this definition is to fix the speed of light in vacuum at exactly $299\ 792\ 458\ \text{m/s}$.

**Velocity of light in air:**

To obtain the velocity of light, one has calculate $\Delta t/\Delta s$. Where $\Delta t$ is the time the light takes to travel the distance $\Delta s$. The distance $\Delta s$ is $2\cdot\Delta x$ because the additional stretch is twice the mirror displacement since the laser beam has to travel to the mirror and back again.

Table 1 gives an example of a measurement:

$$\begin{array}{cccc}
\Delta x \text{ in mm} & \Delta s \text{ in mm} & \Delta t \text{ in ns} & c = \Delta s/\Delta t \\
1000 & 2000 & 6.6 & 3.03 \\
1100 & 2200 & 7.3 & 3.01 \\
1200 & 2400 & 7.9 & 3.03 \\
1300 & 2600 & 8.6 & 3.02 \\
1350 & 2700 & 9.0 & 3.00 \\
1400 & 2800 & 9.3 & 3.01 \\
1450 & 2900 & 9.6 & 3.02 \\
1500 & 3000 & 9.9 & 3.03 \\
1550 & 3100 & 10.3 & 3.01 \\
1600 & 3200 & 10.6 & 3.02 \\
\end{array}$$

av. val.: 3.018

**Velocity of light in water/acrylic glass**

The velocity of light in water or acrylic glass, $c_m$, is measured by comparing it with the velocity of light in air $c_a$ (Fig. 4). In the first measurement (with the medium), the light travels a distance $l_1$ in time $t_1$ ($l_1 = 2x1$).

In the second measurement (no medium), the light travels a distance $l_2 = l_1 + 2\Delta x$ in the same time. This
means that light takes the same time to travel the distance $2\Delta x + 2l_m$ in air as it takes to travel the distance $2l_m$ in the medium.

From this and the definition of the refractive index, it follows directly, that

$$n_m = \frac{(2\Delta x + 2l_m)}{2l_m} = \frac{(\Delta x + l_m)}{l_m}$$

and

$$c_m = \frac{c_a}{n_m}$$

For the water-filled tube, with $l_m = 500$ mm as the length of the water column and a measured $\Delta x$ of 170 mm, this leads to:

$$n = 1.34, \text{ (literature value: } n_{\text{water}} = 1.33)$$

$$c_{\text{water}} = 2.23 \cdot 10^8 \text{ m/s}$$

For the acrylic glass cylinder, with $l_m = 490$ mm and $\Delta x = 240$ mm:

$$n = 1.49, \text{ (literature values are in the range from: } n = 1.48 \text{ to } n = 1.52)$$

$$c_{\text{acrylic glass}} = 2.01 \cdot 10^8 \text{ m/s}$$

**Note**

The evaluation as described here relies completely on the measurements performed with the oscilloscope. No use is made of the displayed values on the velocity of light apparatus.

The reasons for this are mainly didactical ones: The students learn to operate an oscilloscope and they will trust the results more if they measured them themselves this way instead of taking the reading off an apparatus that is made just for this specific measurement. Nevertheless, in many settings (e.g. demonstration in class) it might be quite helpful to use the features built into the apparatus that are described in the manual.